

## CHAPTER 15

### TRAFFIC

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## **TRAFFIC ANALYSIS**

### **General**

A traffic analysis should be made when determining basic number of lanes based on a desired level of service or other specified measure of effectiveness. The review of traffic needs is performed by the Road Design Traffic Engineer and/or the Region Traffic Engineer.

### **Design Year Volume**

The design year for traffic analysis is a minimum of 20 years beyond the anticipated year of project construction. Design year volumes will be calculated by the following methods in the following order:

- 1) Using forecast volumes from an approved planning study.
- 2) Using growth rate factors derived from travel demand forecasting model data supplied by a Metropolitan Planning Organization (MPO) when in an MPO area.
- 3) Applying growth rate factors developed by Transportation Inventory Management. These factors can be derived using values included in the Roadway Information System.

Base year volume data should not be more than 1 year old at the time the traffic analysis is conducted. Exceptions for older data may be made if it is documented that substantial changes in traffic have not occurred since the data was collected.

### **Level of Service and Number of Lanes**

#### **General**

Level of service (LOS) is a qualitative assessment of a highway's operating conditions and refers to a standard measurement that reflects the relative ease of traffic flow on a scale of A to F, stratified by an appropriate performance measure range. The *Highway Capacity Manual* (HCM) defines the ranges for LOS, by facility type.

**Table 15-1** Freeway Level of Service Definitions

<b>Freeways</b>		
<b>LOS</b>	<b>Description</b>	<b>Density (passenger cars / mile / lane)</b>
A	Free-flow operation	$\leq 11$
B	Reasonably free-flow operation; minimal restriction on lane changes & maneuvers	$> 11 - 18$
C	Near free-flow operation; noticeable restriction on lane changes & other maneuvers	$> 18 - 26$
D	Speed decline with increasing flows; significant restriction on lane changes & other maneuvers	$> 26 - 35$
E	Facility operates at capacity; very few gaps for lane changes & other maneuvers; frequent disruptions & queues	$> 35 - 45$
F	Unstable flow; operational breakdown	$> 45$

**Table 15-2** Multilane Principal Arterial Level of Service Definitions

<b>Principal Arterial – Multilane Facility</b>			
<b>LOS</b>	<b>Description</b>	<b>Free-Flow Speed (mph)</b>	<b>Density (passenger cars / mile / lane)</b>
A	Free-flow operation	All	$\leq 11$
B	Reasonably free-flow operation; minimal restriction on lane changes & maneuvers	All	$> 11 - 18$
C	Near free-flow operation; noticeable restriction on lane changes & other maneuvers	All	$> 18 - 26$
D	Speed decline with increasing flows; significant restriction on lane changes & other maneuvers	All	$> 26 - 35$
E	Facility operates at capacity; very few gaps for lane changes & other maneuvers; frequent disruptions & queues	60 55 50 45	$> 35 - 40$ $> 35 - 41$ $> 35 - 43$ $> 35 - 45$
F	Unstable flow; operational breakdown	60 55 50 45	$> 45$ $> 41$ $> 43$ $> 45$

**Table 15-3** Two Lane Principal Arterial Level of Service Definitions

<b>Principal Arterial – Two Lane Facility</b>		
<b>LOS</b>	<b>Description</b>	<b>Percent of Time Spent Following</b>
A	Little platooning; almost unlimited passing opportunities	≤ 35
B	Some platooning; passing demand & opportunities are balanced	> 35 - 50
C	Most vehicles are in a platoon; speeds are reduced	> 50 - 65
D	Platooning significantly increases; passing demand far exceeds passing opportunities	> 65 - 80
E	Facility operates near capacity; almost no passing opportunities	> 80
F	Over capacity; unstable flow; operational breakdown	N / A

**Table 15-4** Minor Arterial & Collector Level of Service Definitions

<b>Minor Arterial &amp; Collector – Two Lane Facilities</b>		
<b>LOS</b>	<b>Description</b>	<b>Percent of Time Spent Following</b>
A	Little platooning; almost unlimited passing opportunities	≤ 40
B	Some platooning; passing demand & opportunities are balanced	> 40 - 55
C	Most vehicles are in a platoon; speeds are reduced	> 55 - 70
D	Platooning significantly increases; passing demand far exceeds passing opportunities	> 70 - 85
E	Facility operates near capacity; almost no passing opportunities	> 85
F	Over capacity; unstable flow; operational breakdown	N / A

**Table 15-5** Signalized Intersection Level of Service Definitions

<b>Signalized Intersections</b>		
<b>LOS</b>	<b>Description</b>	<b>Intersection Control Delay (seconds / vehicle)</b>
A	Very minimal queuing; excellent corridor progression	≤ 10
B	Some queuing; good corridor progression	> 10 - 20
C	Regular queuing; not all demand may be serviced on some cycles (cycle failure)	> 20 - 35
D	Queue lengths increased; routine cycle failures	> 35 - 55
E	Majority of cycles fail	> 55 - 80
F	Volume to capacity ratio near 1.0; very long queues, almost all cycles fail	> 80

**Table 15-6** ALL-WAY STOP Controlled Intersection Level of Service Definitions

<b>ALL-WAY STOP Controlled Intersections</b>		
<b>LOS</b>	<b>Description</b>	<b>Intersection Control Delay (seconds / vehicle)</b>
A	Queuing is rare	≤ 10
B	Occasional queuing	> 10 - 15
C	Regular queuing	> 15 - 25
D	Queue lengths increased	> 25 - 35
E	Significant queuing	> 35 - 50
F	Volume to capacity ratio approaches 1.0; very long queues	> 50

**Table 15-7** TWO-WAY STOP Controlled Intersection Level of Service Definitions

<b>TWO-WAY STOP Controlled Intersections</b>		
<b>LOS</b>	<b>Description</b>	<b>Approach Control Delay <sup>1</sup> (seconds / vehicle)</b>
A	Queuing is rare	≤ 10
B	Occasional queuing	> 10 - 15
C	Regular queuing	> 15 - 25
D	Queue lengths increased	> 25 - 35
E	Significant queuing	> 35 - 50
F	Volume to capacity ratio approaches 1.0; very long queues	> 50

<sup>1</sup> Note that for TWSC Intersections, no intersection control delay is calculated.

**Table 15-8** Roundabout Level of Service Definitions

Roundabouts		
LOS	Description <sup>1</sup>	Control Delay (seconds / vehicle)
A	N/A	≤ 10
B	N/A	> 10 - 15
C	N/A	> 15 - 25
D	N/A	> 25 - 35
E	N/A	> 35 - 50
F	Volume to capacity ratio approaches 1.0	> 50

<sup>1</sup> Research for driver perception of quality of service at roundabouts is pending and no general descriptions have been adopted.

## Roadway Segments

For Construction/Reconstruction projects Table 15-9 and Table 15-10 are used as the basis for determination of capacity and basic number of lanes based on a typical 20 year average daily traffic (ADT) projection beyond the anticipated year of project construction. The highest LOS as practical, which may be higher than the values listed in Table 15-9, should be provided depending on varying conditions as noted on the following page.

**Table 15-9** Level of Service Guidelines

Functional Classification <sup>1</sup>	Highway Type				
	Rural Level	Rural Rolling	Rural Mountainous	Urban <sup>2</sup>	
				Desirable	Minimum
Freeways (Interstate & Expressways, mainline, merge points, diverge points, and weave area)	B	B	C	B	C
Principal Arterial	B	B	C	C	D
Minor Arterial <sup>3</sup>	B	B	C	C	D
Collector <sup>3</sup>	C	C	D	C	D

<sup>1</sup> For functional classifications, refer to the current edition of the *SDDOT Highway Needs and Project Analysis Report*.

<sup>2</sup> Urban includes highways within the city limits of a town or city with consideration of the growth areas beyond city boundaries. The use of level of service D should only be considered in heavily developed (fully built out) sections of metropolitan areas.

<sup>3</sup> Two lane Minor Arterials & Collectors should be considered Class II highways when utilizing the current edition of the *HCM*.

Note that the values shown in Table 15-10 are only to be used as general guidance for the total number of lanes based on the LOS guidelines noted above. The design determination of the total number of lanes shall be determined by a traffic analysis that incorporates the following factors:

- Terrain (level, rolling or mountainous)
- Volume of left turn movements
- Traffic signals
- Number of access points
- Major intersecting roadways

**Table 15-10** Estimated Number of Lanes

Total Number of Lanes	Total Design Year ADT <sup>1</sup>	
	Rural Level	Urban
2	< 8,000	< 2,500
3	<sup>2</sup>	2,500 to 16,000
4	8,000 to 20,000 <sup>3</sup>	<sup>3</sup>
5	<sup>2</sup>	16,000 to 30,000
6	> 20,000 <sup>4</sup>	> 30,000 <sup>4</sup>

<sup>1</sup> Construction/Reconstruction projects are designed based on a typical 20 year ADT projection beyond the anticipated year of project construction.

<sup>2</sup> Continuous left turn lanes may be considered based on left turn volumes and/or when intersections and/or approaches are closely spaced together.

<sup>3</sup> Undivided sections may be used if left turn movements are low and there is no crash history, otherwise consider installing a median or 5 lane section.

<sup>4</sup> Medians should be used.

## Conventional Intersections and Interstate Ramp Terminals

Lane requirements at intersections shall be determined using the methodologies of the HCM.

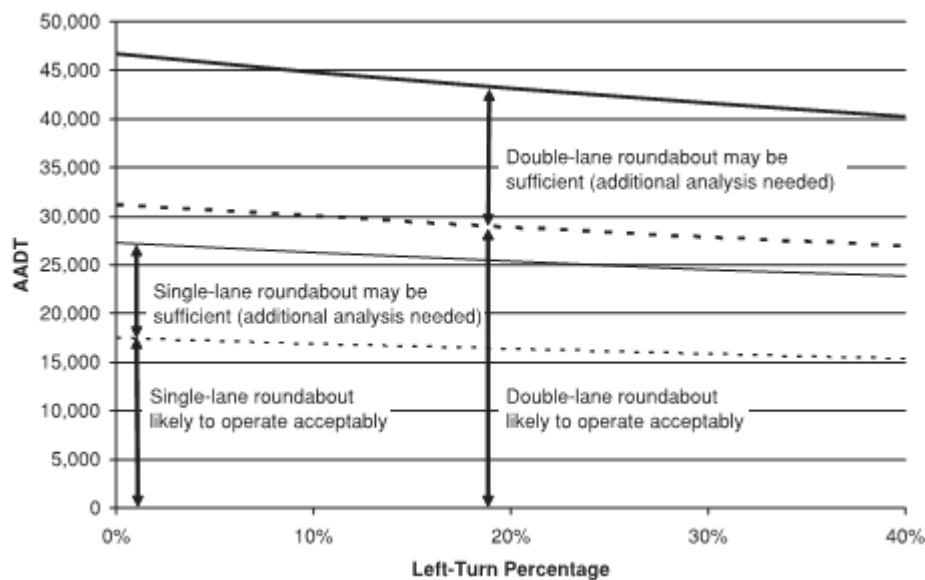
For a signalized intersection, the desired overall intersection LOS is C; a minimum LOS of D may be appropriate for urbanized areas. Additionally, each approach to the intersection should be designed to have the highest LOS practical.

Freeway ramp termini are typically analyzed in accordance with Chapter 23 (Ramp Terminals and Alternative Intersections) of the HCM and if unsignalized, analyzed in accordance with Chapter 20 (Two-Way Stop-Controlled Intersections) of the HCM. The ramp termini should be maintained at a LOS C or better.

## Roundabouts

Lane requirements at roundabouts shall be determined using the methodology of the HCM.

For planning purposes, the number of lanes at a roundabout may be estimated by the following:



**Figure 15-1** Estimated Number of Roundabout Lanes  
Source: *NCHRP Report 672* (Roundabouts: An Informational Guide)

**Table 15-11** Estimated Number of Roundabout Entry Lanes

Volume Range, vph (sum of entering & conflicting volumes)	Number of Lanes Required
0 to 1,000	1
1,000 to 1,300	Upper threshold for 1 lane, more detailed analysis required. 2 lanes satisfactory.
1,300 to 1,800	2
1,800+	Detailed analysis required.

Source: *NCHRP Report 672* (Roundabouts: An Informational Guide)

The desired roundabout Level of Service is C; the minimum Level of Service is D.

For detailed turn lane, roundabout, and median geometric design information refer to Chapter 7 – Cross Sections or Chapter 12 – Intersections.

## **TURN LANE WARRANTS**

### **Turn Lane Study Guidelines**

At a minimum, turn lane analysis reports should include the following:

- A thorough evaluation of each of the warrant criteria.
- Discussion of access management considerations.
- Recommendations as to whether or not turn lanes are appropriate. Note that even though conditions may or may not meet certain criterion, the ultimate deciding factor is the engineer's judgment. Factors that could influence the decision include conflict analysis results, benefit/cost analysis results, right-of-way cost considerations, constructability, etc.
- The recommended storage length if a turn lane is appropriate. The estimated 95<sup>th</sup> percentile queue value should be used for the recommended length. Queue values should be determined using an acceptable analysis software method.

### **Left Turn Lane Criteria – Unsignalized Intersections**

Generally, left turn lanes should be considered (1) when the hourly volume of turns has a significant negative effect on traffic operations, or, (2) when historical crash analysis shows that a crash trend could be correctable by providing a turn lane.

### **Left Turn Lane Evaluation Process**

- A left turn lane should be installed if Criterion 1 (Volume), 2 (Crash), or 3 (Special Cases) are met; and
- The left turn lane complies with access management spacing standards; and
- The left turn lane conforms to appropriate design guidelines.

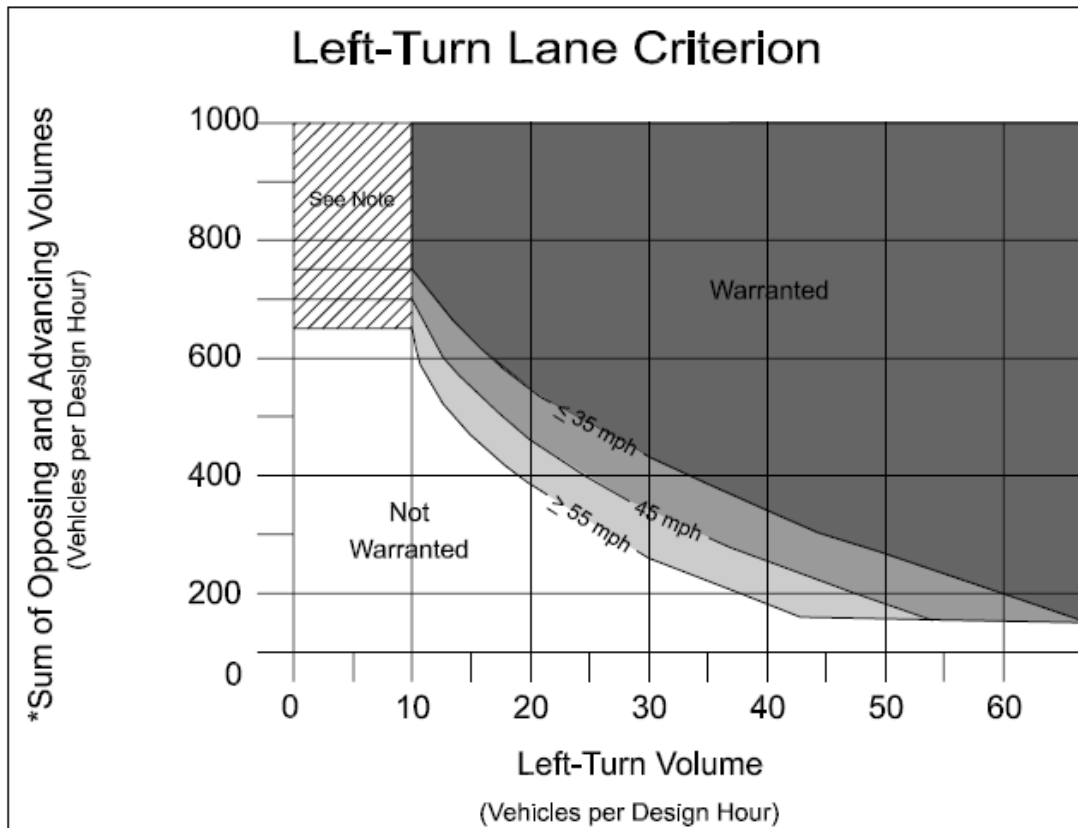
### **Criterion 1: Vehicular Volume**

The vehicular volume criterion is intended for application where the volume of intersecting traffic is the principal reason for considering installation of a left turn lane. The volume criteria are determined by the Texas Transportation Institute (TTI) curves in Figure 15-2.

## **Criterion 2: Crash Experience**

The crash experience criterion is satisfied when either Condition 1 or 2 are met and Condition 3 is met:

1. A history of crashes of the type susceptible to correction by a left turn lane (e.g. rear-end crashes involving turning vehicles). A separate left turn lane may be warranted if three or more reported intersection related crashes occur within a 12 month period. The geometry for warranted turn lanes shall be used for locations meeting these criteria (see Chapter 12 - Intersections).
2. An economic analysis using predictive measures consistent with the AASHTO Highway Safety Manual (HSM) shows a benefit/cost ratio  $\geq 1.0$  and at least two crashes in the last ten years are of the type susceptible to correction by a left turn lane (e.g. rear-end crashes involving turning vehicles), or based on the Highway Safety Engineer's recommendation to add a turn lane. The geometry for warranted turn lanes shall be used for locations meeting these criteria (see Chapter 12 - Intersections).
3. The installation of the left turn lane does not adversely impact the operations of the intersection.



Source: Oregon DOT Analysis Procedures Manual 2008

$$*(\text{Advancing Vol/ \# of Advancing Through Lanes}) + (\text{Opposing Vol/ \# of Opposing Through Lanes})$$

Note: The criterion is not met from zero to ten left turn vehicles per hour, but careful consideration should be given to installing a left turn lane due to the increased potential for crashes in the through lanes. While the turn volumes are low, the adverse safety and operational impacts may require installation of a left turn. The final determination will be based on a field study.

**Figure 15-2 Left Turn Lane Volume Warrant**

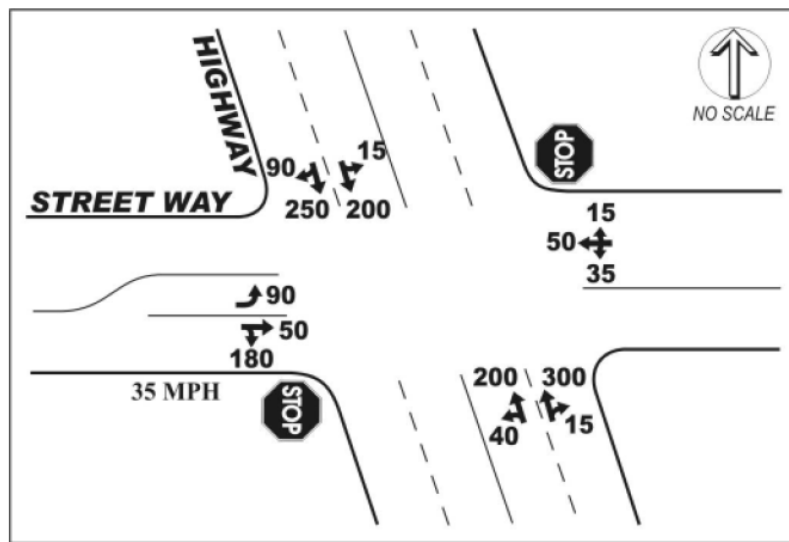
### **Criterion 3: Special Cases**

1. Railroad Crossings: If a railroad is parallel to the roadway, then the likelihood of train movements preventing left turns and creating stopped queues on the highway should be taken into consideration. The provided left turn lane storage length will be dependent on the duration that the side road is closed, the expected number of vehicle arrivals, and the location of the crossing. The analysis should consider all of the variables influencing the design of the left turn lane, and may allow a design for conditions other than the worst case storage requirements, provided safety is not compromised.
2. Geometric/Safety Concerns: Sight distance, alignment, operating speed, adjacent access points, and other safety related concerns should be taken into consideration.

3. Non-Traversable Median: A left turn lane may be considered to be installed at a break in a non-traversable median where left turns are not prohibited and either of the following conditions exist:
  - a. If Criterion 1 (Vehicular Volume) is not met but there is a significant amount of left turn movements; or
  - b. If Criterion 2 (Crash Experience) is not met but there has been a pattern of crashes that has occurred, and a left turn lane would prevent or limit those types of crashes to occur if installed.

### Left Turn Lane Volume Criterion Example

Figure 15-2a shows an unsignalized intersection with a shared through-right lane and a shared through-left lane on the highway. The peak hour volumes and lane configurations are shown in the figure. The 85<sup>th</sup> percentile speed is 45 mph. Does the intersection meet the volume criterion for a left turn lane in either the NB or SB direction?



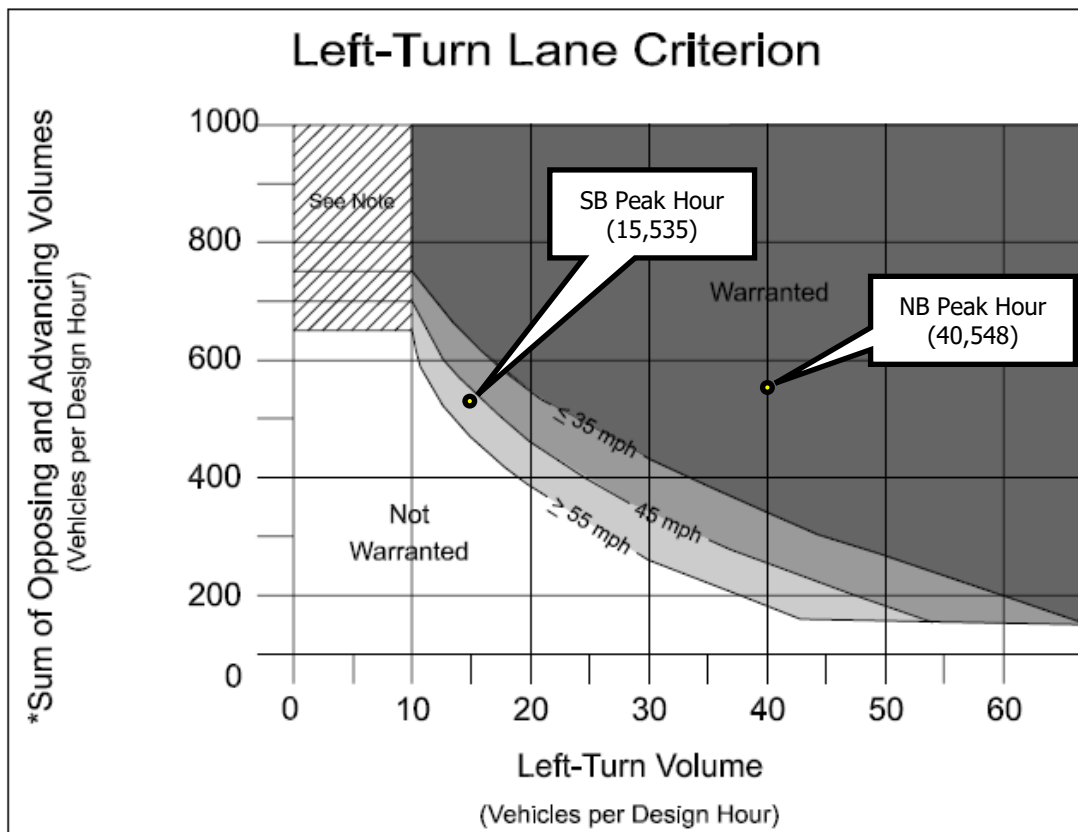
**Figure 15-2a Left Turn Lane Example Volumes**

- Southbound: The SB advancing volume is 555 (90+250+200+15) and the NB opposing volume is 515 vehicles (the opposing left turns are not counted as opposing volumes). The volume for the Y-axis on Figure 15-2 is determined using the equation:

$$\begin{aligned}
 \text{Y-axis volume} &= ((\text{Advancing Vol}/\# \text{ of Advancing Lanes}) + \\
 &\quad (\text{Opposing Vol}/\text{Number of Opposing Lanes})) \\
 &= (555/2 + 515/2) = 535
 \end{aligned}$$

To determine if the SB left turn volume criterion is met, use the 45 mph curve in Figure 15-2, 535 for the y-axis, and 15 left-turns for the x-axis. The volume criterion is not met in the SB direction.

- **Northbound:** The NB advancing volume is 555 (40+200+300+15) and the SB opposing volume is 540 vehicles (the opposing left turns are not counted as opposing volumes). The volume for the Y-axis on Figure 15-2 is  $(555/2 + 540/2) = 548$ . To determine if the SB left turn volume criterion is met, use the 45 mph curve in Figure 15-2, 548 for the y-axis, and 40 left turns for the x-axis. The volume criterion is met in the NB direction.



Source: Oregon DOT Analysis Procedures Manual 2008

$$\frac{*(Advancing\ Vol/ \# \text{ of Advancing Through Lanes}) + (Opposing\ Vol/ \# \text{ of Opposing Through Lanes})}{2}$$

Note: The criterion is not met from zero to ten left turn vehicles per hour, but careful consideration should be given to installing a left turn lane due to the increased potential for crashes in the through lanes. While the turn volumes are low, the adverse safety and operational impacts may require installation of a left turn. The final determination will be based on a field study.

**Figure 15-2b** Left Turn Lane Example Criterion Graph

## **Right Turn Lane Criteria – Unsignalized Intersections**

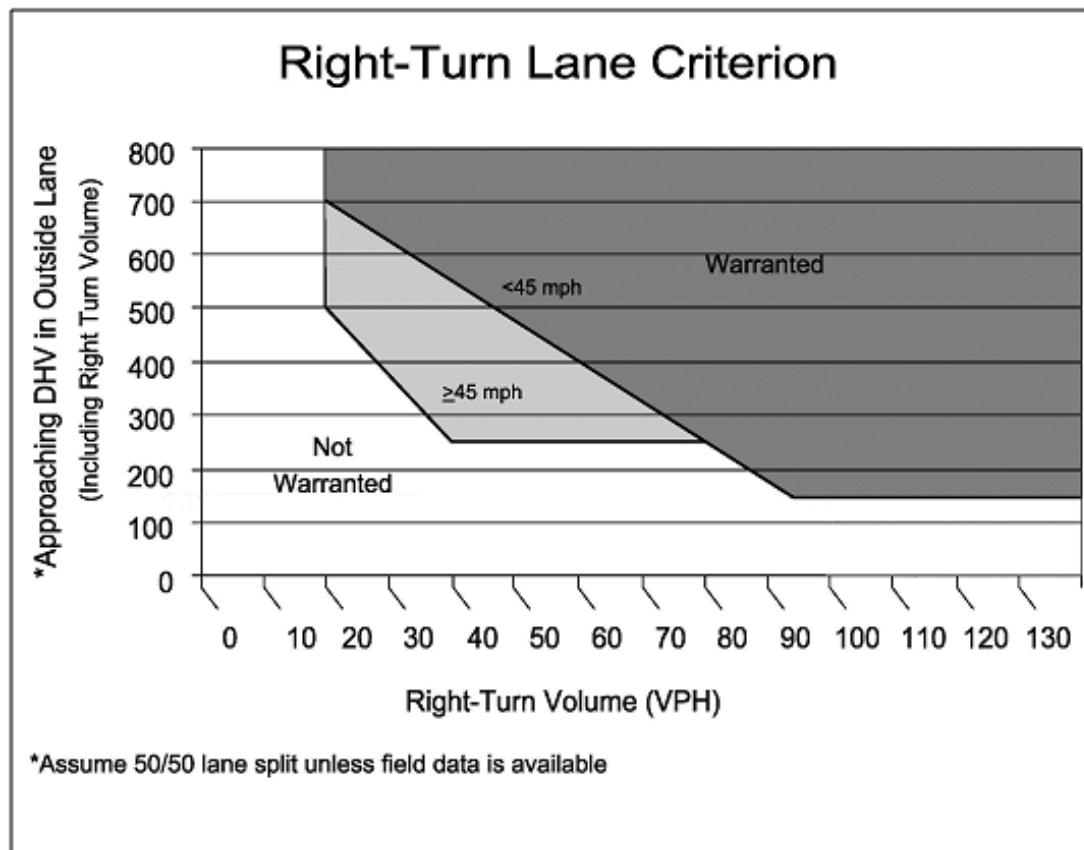
The purpose of a right turn lane at an unsignalized intersection is to reduce the speed differential between the right turning vehicles and the other vehicles on the roadway. Research has shown that this will increase roadway capacity and reduce certain types of crashes.

### **Right Turn Lane Evaluation Process**

- A right turn lane should be considered if criterion 1 (Volume), 2 (Crash), or 3 (Special Cases) is met; and
- The right turn lane complies with access management spacing standards; and
- The right turn lane conforms to the appropriate design guidelines.

### **Criterion 1: Vehicular Volume**

The vehicular volume criterion is intended for application where the volume of intersecting traffic is the principal reason for considering installation of a right turn lane. The vehicular volume criterion is determined using the curve in Figure 15-3.



**Figure 15-3** Right Turn Lane Volume Warrant

## Criterion 2: Crash Experience

The crash experience criterion is satisfied when either Condition 1 or 2 are met and Condition 3 is met:

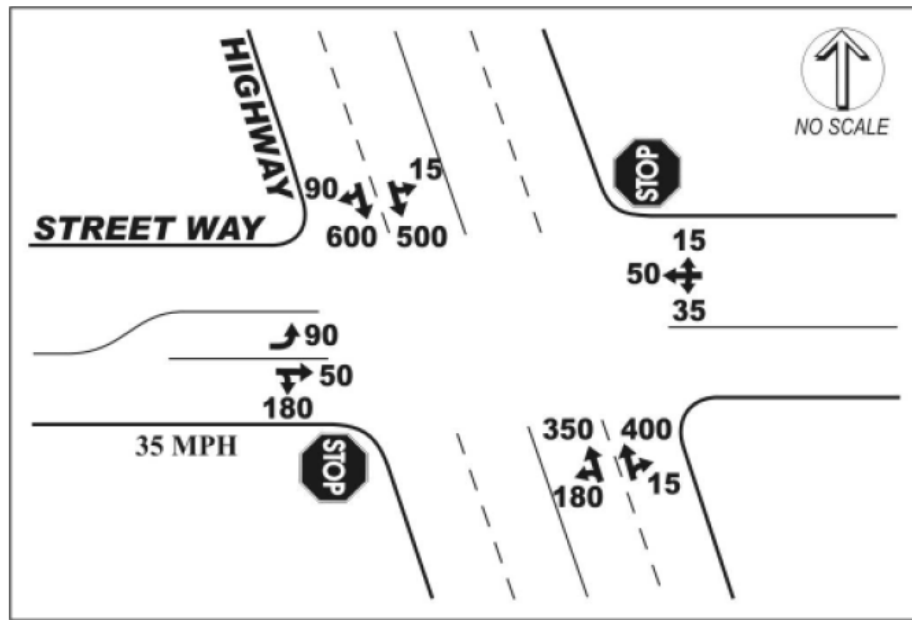
1. A history of crashes of the type susceptible to correction by a right turn lane (e.g. rear-end crashes involving turning vehicles). A separate right turn lane may be warranted if three or more reported intersection- related crashes occur within a 12 month period. The geometry for warranted turn lanes shall be used for locations meeting these criteria (see Chapter 12 -Intersections).
2. An economic analysis using predictive measures consistent with the HSM shows a benefit/cost ratio  $\geq 1.0$  and at least two crashes in the last ten years are of the type susceptible to correction by a left turn lane (e.g. rear-end crashes involving turning vehicles), or based on the Highway Safety Engineer's recommendation to add a turn lane. The geometry for unwarranted turn lanes shall be used for locations meeting these criteria (see Chapter 12 - Intersections).
3. The installation of the right turn lane does not adversely affect bicyclists or pedestrians.

## Criterion 3: Special Cases

1. Railroad Crossings: If a railroad is parallel to the roadway, then the likelihood of train movements preventing right turns and creating stopped queues on the highway should be taken into consideration. The provided right turn lane storage length will be dependent on the duration that the side road is closed, the expected number of vehicle arrivals, and the location of the crossing. The analysis should consider all the variables influencing the design of the right turn lane and may allow a design for conditions other than the worst-case storage requirements, provided safety is not compromised.
2. Geometric/Safety Concerns: Sight distance, alignment, operating speeds, adjacent access points and other safety related concerns should be taken into consideration.

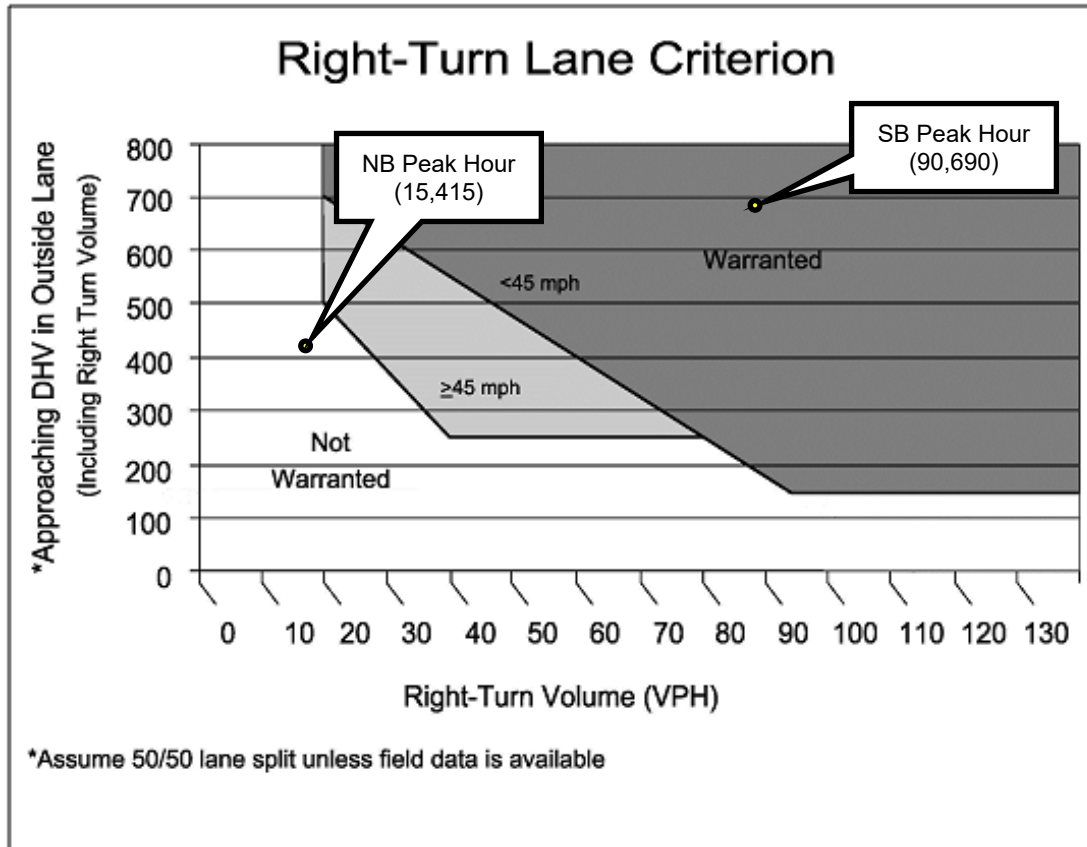
## Right Turn Lane Volume Criterion Example

Figure 15-3a shows an unsignalized intersection with a shared through-right lane and a shared through-left lane on the highway. The peak hour volumes and lane configurations are shown in the figure. The 85<sup>th</sup> percentile speed is 45 mph. Does the intersection meet the volume criterion for a right turn lane in either the NB or SB direction?



**Figure 15-3a** Right Turn Lane Example Volumes

- The NB outside lane has 400 through vehicles and 15 right turning vehicles for a total of 415 vehicles. Using the 45 mph curve in Figure 15-3, along with 415 approaching vehicles and 15 right turning vehicles we find that the vehicle volume criterion is not met.
- The SB outside lane has 600 through vehicles and 90 right turning vehicles for a total of 690 vehicles. Using the 45 mph curve in Figure 15-3, along with 690 approaching vehicles and 90 right turning vehicles we find the vehicular volume criterion is met.



**Figure 15-3b** Right Turn Lane Example Criterion Graph

### **Turn Lane Criteria – Signalized Intersections**

The need for turn lanes at signalized intersections is determined differently than at unsignalized intersections. Left and right turn lanes at signalized intersections should be considered if:

1. A reduction in intersection delay can be demonstrated. Intersection analyses shall be in accordance with the HCM; or
2. The benefit/cost ratio for the improvement is greater than 1.0.

The operational analysis of dual turn lanes shall take into account forecast imbalances in lane utilization.

## TRAFFIC SIGNAL CONTROL

### General

The objective of traffic signal control is to provide for safe and efficient traffic flow at intersections, along routes and within street networks. If traffic signals are warranted, properly located, and properly maintained, then the following benefits are typically realized:

1. Reduced frequency of certain types of crashes, especially right angle and pedestrian types.
2. Improved traffic flow and capacity of the intersection.
3. Interruption of heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to use the intersection.

### Traffic Signal Terms

**Coordination** – Establishment of a definite timing relationship between two or more traffic signals for facilitating traffic flow along a highway.

**Cycle Length** – The total time in seconds required for one complete sequence of servicing all phases at their maximum allotted time.

**Detector** – A device for indicating the presence or passage of vehicles or pedestrians.

**Free Operation** – Fully actuated, non-coordinated operation of a traffic signal.

**Interval** – A portion of the signal cycle during which the indications do not change.

**Phase** – A traffic signal display with its own set of timings that control a specific vehicle or pedestrian movement, e.g. northbound left turn phase, eastbound through phase, etc.

**Phase Sequence** – The order in which a controller serves individual phases.

**Preemption** – A term used when the normal signal sequence at an intersection is interrupted and/or altered in deference to a special situation such as the passage of a train or granting the right of way to an emergency vehicle.

**Traffic Signal Controller** – The device that controls the sequence and duration of phases.

## **Signal Poles & Signal Heads (Vehicle & Pedestrian)**

All new signal poles shall be galvanized steel unless otherwise agreed upon during the project development process. Pedestal signal poles should be aluminum with a frangible transformer base. Whenever possible, signal poles should be placed at least seven (7) feet from the back of the curb and gutter to the center of the pole. Note however, that pole placement must comply with ADA design guidelines.

The number of signal heads and signal head placement shall be in accordance with the Manual on Uniform Traffic Control Devices (MUTCD). The SDDOT typically installs any signal heads shown as optional in the MUTCD.

All pedestrian signal systems shall be accessible pedestrian signals. Pedestrian push buttons shall be located in accordance with the MUTCD and shall comply with ADA design guidelines (see Chapter 16- Miscellaneous). Push buttons may be placed on signal poles or pedestal signal poles if ADA guidelines are met.

Pedestrian signal heads should be installed a maximum of 10-feet laterally from the outside of the crosswalk. A single 16-inch x 18-inch pedestrian head should be used. A pedestal signal pole should be used if necessary to achieve the desired offset distance.

## **Traffic Signal Operation**

Traffic signal operation is broadly classified as either pretimed or actuated. A second defining parameter is whether the signal is isolated or part of a coordinated system.

Pretimed operation is applicable to both isolated and coordinated contexts. In pretimed operation the controller uses a constant, fixed cycle length, and preset phase times. This type of operation is best suited for locations with predictable volumes and traffic patterns, such as central business districts and coordinated systems.

There are three types of actuated operation:

Semi-actuated operation uses detectors on the minor street approaches. This type of control is generally used at intersections where traffic on the major street is heavy and arrivals are random on the minor street. Semi-actuated control can be used for both isolated signals and coordinated systems.

Fully actuated operation requires detectors on all approach lanes. Phase times are variable and depend upon the number of vehicles detected. All phases have a pre-determined maximum time that cannot be exceeded. Fully actuated control is only used for isolated signals

Adaptive signal control (ASC) utilizes a central control (generally a computer) to continuously monitor traffic demand, evaluate performance, and vary signal timing, all on a real-time basis. ASC is used when there is significant variability in traffic demand, beyond that which traditional coordinated timing plans can satisfactorily respond.

### **Vehicle Detectors**

Varieties of detector technologies exist and are deployed throughout the State system. Each type has its advantages and disadvantages, however, for new construction the preferred detection method is the pre-formed inductive loop. For unique design situations or retrofit conditions, magnetometer detectors, radar detection, video detection, or microwave detection may be a more cost effective and less traffic-disruptive alternative to loops.

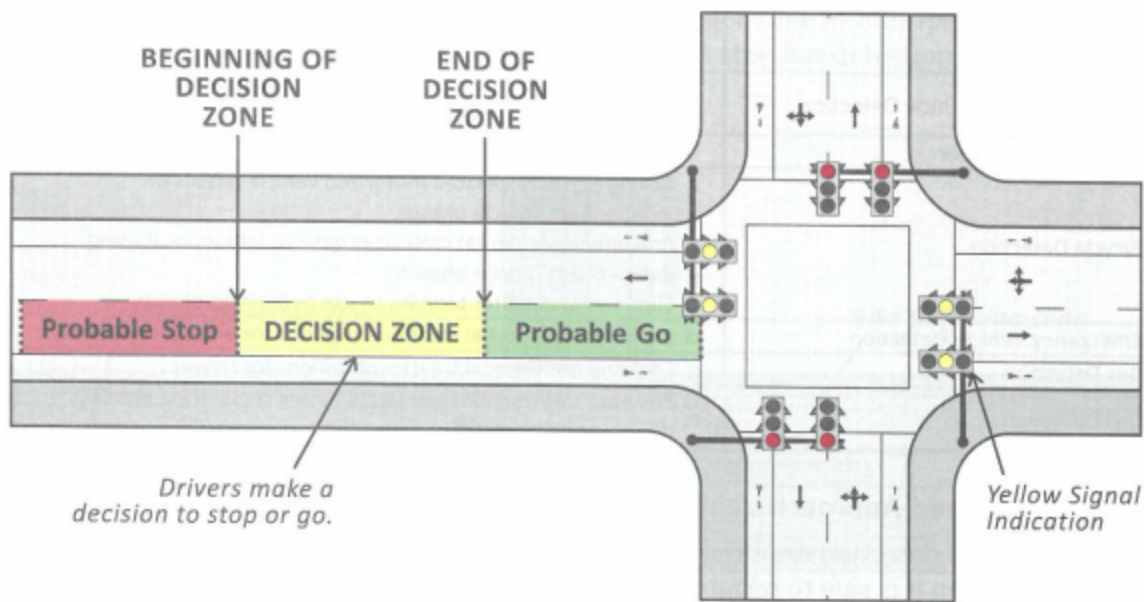
For semi-actuated control and protected left turn phases, the detection zone should be located at the front of the side street or left turn lane stop bar.

In fully actuated control at low speed approaches, detection zones for extension timings should be located on the mainline as noted in Table 15-12.

**Table 15-12** Detector Placement at Low Speed Approaches in Fully Actuated Control

Approach Speed (mph)	Stop Line to Leading Edge of Loop (ft)	Minimum Green (sec)	Actuations Before Extension	Seconds per Actuation	Maximum Added Initial (sec)	Vehicle Extension (sec)
20	90	5	1	2	10	3
25	110	5	1	2	12	3
30	140	5	1	2	14	3
35	160	10	2	2	16	3
40	180	10	2	2	18	3

Dilemma zone detection is used at fully actuated signals with approach speeds greater than 40 mph. At higher speeds, it may be difficult for the driver to decide whether to stop or proceed when faced with a yellow change indication; an abrupt stop may result in a rear-end collision, while the decision to proceed through the intersection may result in a red light violation. The limits of where this indecision occurs are known as the dilemma zone and are illustrated on Figure 15-4. The concept of dilemma zone detection is simply to detect vehicles as they enter the dilemma zone and then have the controller extend the green until the vehicle clears the dilemma zone.



**Figure 15-4** Dilemma Zone

Source: *NCHRP Report 812 (Signal Timing Manual Second Edition)*

Empirical research has shown that irrespective of speed, the dilemma zone begins 5.5 seconds from the stop line and ends 2.5 seconds from the stop line. The values of  $D_{BZ}$  and  $D_{EZ}$  should be based on these times and on the 85<sup>th</sup> percentile speed of the approach. If the 85<sup>th</sup> percentile speed is unknown, then the speed used in calculations shall be the posted speed plus 7 mph.

Dilemma zone detection should be provided for three different speeds: 85<sup>th</sup> percentile, 5 mph under the 85<sup>th</sup> percentile speed, and 5 mph over the 85<sup>th</sup> percentile speed.

Whenever advance detection is used, the designer should consider implementing gap reduction into the signal's operation. Gap reduction allows for more efficient gap outs during periods of low approach volume.

### **Signal Preemption and Priority Control**

In certain locations, it is desirable to preempt the normal operation of a traffic signal to facilitate the clearance of traffic that might be backed up onto an active railroad track or to facilitate the movement of emergency vehicles. The decision to provide emergency vehicle preemption is made in conjunction with the local municipality during the scoping process. The decision to provide railroad preemption should be by the designer and should consider MUTCD requirements.

Railroad preemption involves interconnecting the traffic signal controller with adjacent railroad signaling equipment. Emergency vehicle preemption typically involves a vehicle-mounted emitter sending a signal to a receiver connected to the traffic signal controller. An alternative emergency vehicle preemption system uses the sound of the siren as a signaling medium.

In both railroad and emergency vehicle preemption, once the traffic signal controller receives a notification, it begins to execute a programmed set of steps to flush the intersection approach that crosses the railroad track or to set the signal displays to facilitate the passage of the emergency vehicle. Where conflicting preemptions occur, train preemption receives first priority, emergency vehicles second priority. All programmed preemption steps and timings in the controller shall be developed as per the MUTCD.

### **Flash Operation**

There are two reasons for flash operation of a traffic signal:

1. To improve the efficiency of the intersection when traffic volumes are low. During periods of the day with low traffic volume, a signal may be more efficient when operated in flash operation. Careful consideration of intersection sight distance and other factors should be made before deciding to use flash operation within a traffic signal's normal programmed operation.
2. To provide a safe method of intersection control when a traffic signal malfunctions.

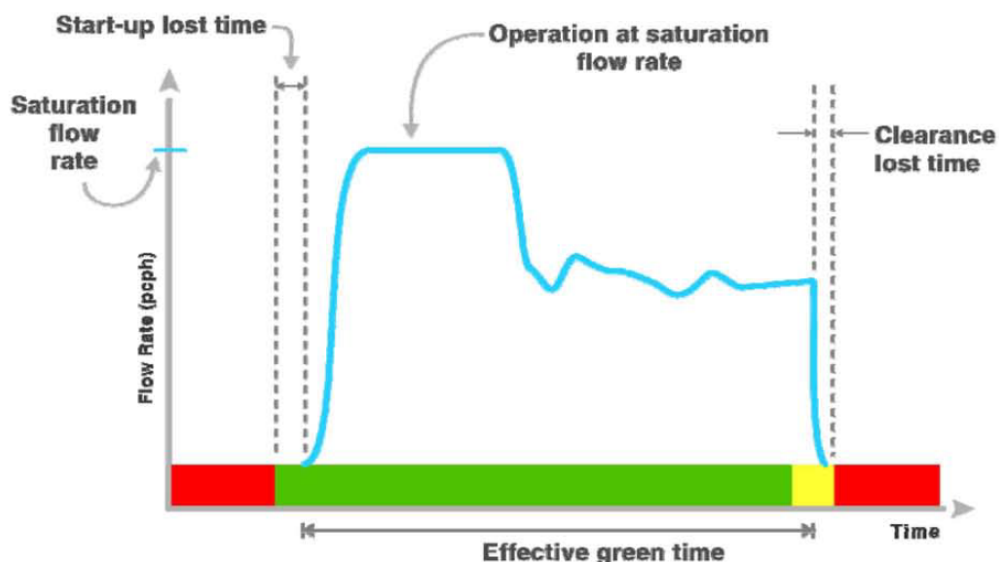
When a signal is programmed to operate in flash mode, the pattern is typically yellow (major street) and red (minor street). Specific details about flash operation should be as per the MUTCD. Flash operation should begin and end at the same time for all flashed signals in an area, so as not to violate drivers' expectations.

When a traffic signal experiences a malfunction, the flash pattern is typically red for all directions. Exceptions may be necessary due to the proximity of a railroad crossing, limited intersection spacing in a corridor, unusual traffic patterns, or other site-specific reasons.

## TRAFFIC SIGNAL PHASING & TIMING

### Traffic Signal Phasing

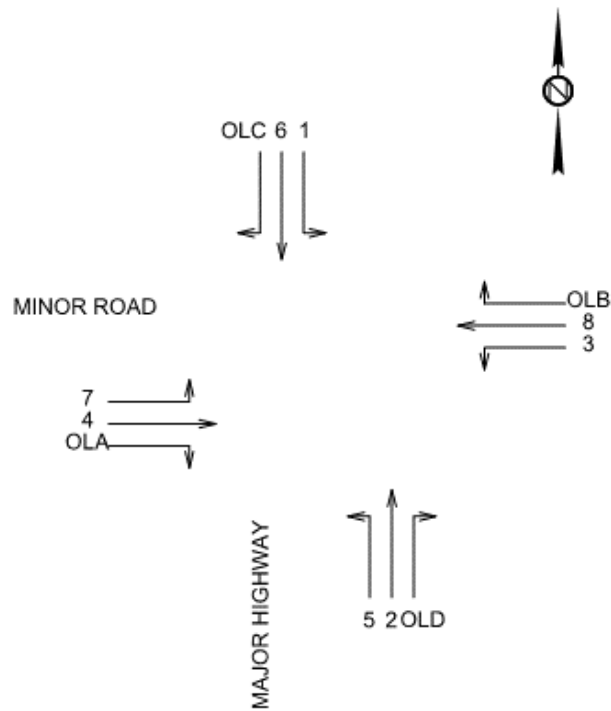
The number of phases and phase sequence depends upon the geometry of the intersection, vehicular traffic volumes, directional movements, and pedestrian crossing requirements. The number of phases should be kept to a minimum to maximize intersection efficiency. Each additional signal phase reduces the effective green time available for the movement of traffic flows (increases lost time due to starting and stopping delays) as illustrated in Figure 15-5.



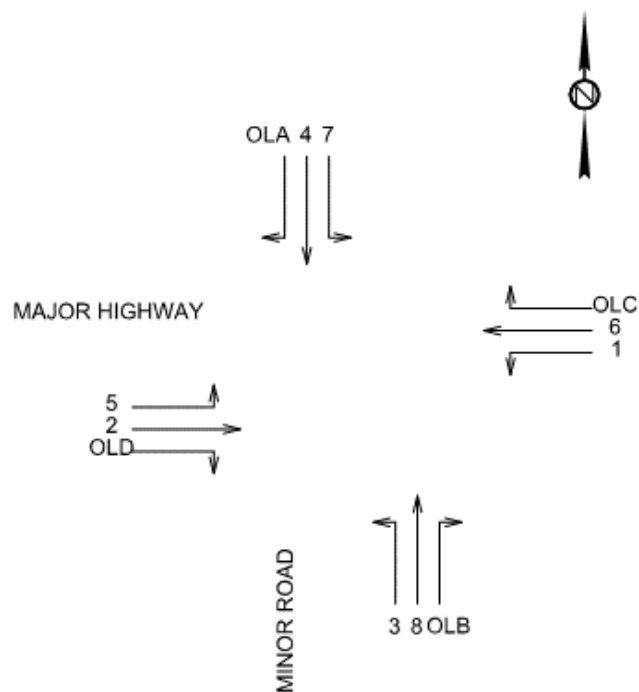
**Figure 15-5** Typical Flow Rates at a Signalized Movement

Source: *FHWA Signal Timing Manual*

The numbering of phases shall be consistent with Figures 15-6 and 15-7.



**Figure 15-6** Phase Numbering, Major Highway N/S



**Figure 15-7** Phase Numbering, Major Highway E/W

## **Left Turn Phasing**

Dedicated left turn lanes should be provided on state highways at signalized intersections. The need for dedicated left turn lanes on the minor road should be determined by a traffic analysis. There are five phasing options for how left turns are accommodated at a traffic signal:

1. Permissive Only Operation – a green ball or flashing yellow arrow is displayed to left turning vehicles and they must yield to oncoming traffic and conflicting pedestrians before completing their turn. No green arrow is provided for left turns.
2. Protected / Permissive Operation – left turning vehicles are given a green arrow that assigns them the right-of-way to complete their turn. They are also allowed to turn left when a flashing yellow arrow or green ball is displayed, but must yield to oncoming traffic. The protected arrow phase may come before the green ball (called a leading left turn) or after it (called a lagging left turn).
3. Protected Only Operation – left turning vehicles are only given a green arrow that assigns them the right-of-way to complete their turn. The protected arrow phase may come before the green ball for through traffic (called a leading left turn) or after it (called a lagging left turn).
4. Split Phase Operation – all movements on an approach are given the right of way to complete their movements with all other opposing directions of traffic given a red display. Split phasing may be used in some rare instances, but is generally not desirable as it not an efficient way to operate signals.
5. Prohibited Left Turn Operation – left turns are not allowed at the signal.

In general, protected left-turn phases reduce the available green time for through traffic and tend to increase total intersection delay. The decision to provide a protected left-turn phase should follow the procedure outlined in NCHRP Report 812 (Signal Timing Manual Second Edition). The traffic signal should be designed for protected left turn phases if it is anticipated that the phases will be justified within 2 years of the signal being installed. If protected left turn phasing is justified later than 2 years after construction, then the appropriate conductors should be provided in the design and the mast arm sized appropriately.

Care should be taken when considering the use of a lagging left turn phase on only one approach to avoid creating a yellow ball trap. The trap is created when one left turn approach sees a yellow ball at the conclusion of the permissive turn phase, but the opposing through approach continues to see a green ball. Left turning traffic seeing the yellow ball may attempt to complete their left turn assuming that the opposing through movement will also be stopping. A comprehensive discussion of the yellow ball trap and how to mitigate it can be found in the NCHRP Report 812 (Signal Timing Manual Second Edition). The flashing yellow arrow operation is the most common way to eliminate a yellow ball trap.

### **Cycle Length**

The designer should strive to use the shortest cycle length possible, because short cycle lengths generally result in the lowest overall intersection delay. The selection of an appropriate cycle length must consider the proper vehicle clearance times along with the proper pedestrian clearance times. A cycle length of 140 seconds should be the maximum used, irrespective of the number of phases.

### **Minimum Green Time**

To meet driver expectations, minimum green times should be as shown in Table 15-13. At locations with significant truck traffic, consideration should be given to either providing minimum green times higher than presented or installing additional vehicle detectors to compensate for the longer vehicle headways.

**Table 15–13** Typical Minimum Green Time

<b>Phase Type</b>	<b>Facility Type</b>	<b>Minimum Green (seconds)</b>
Through	Major Arterial, > 40 mph	10 - 15
	Major Arterial, ≤ 40 mph	7 - 15
	Minor Arterial	4 - 10
	Collector, Local, Driveway	2 - 10
Left Turn	All	2 - 5

Source: NCHRP Report 812 (Signal Timing Manual Second Edition)

While the maximum green time is determined by analysis, generally it should be at least 5-seconds greater than the minimum green time to allow for some phase extension.

## **Phase Change Interval**

The phase change interval is defined as the yellow phase time and the all-red phase time. The purpose of the change interval is to advise drivers that their phase is ending and to provide adequate time for them either to come to a safe stop prior to entering the intersection, or to allow adequate time for vehicles legally entering the intersection to clear the intersection. South Dakota law permits vehicles to enter an intersection on a yellow display.

The following equations are used to determine the phase change interval :

$$\text{Yellow Time (sec)} = t + \frac{1.47V}{(2a + 64.4 g)}$$

### **Equation 15-1 Yellow Time**

Source: *NCHRP Report 731*

Where:

$t$  = perception/reaction time of driver (s); *set at 1.0 s*

$V$  = 85<sup>th</sup> percentile speed (mph); *if not available use posted speed plus 7 mph for through phases or posted speed minus 5mph for left turn phases*

$a$  = deceleration rate (ft/s<sup>2</sup>); *set at 10 ft/s<sup>2</sup>, consider using 7 ft/s<sup>2</sup> for movements with significant truck traffic*

$g$  = approach grade; percent of grade divided by 100 (add for upgrade and subtract for downgrade)

$3 \text{ sec} \leq \text{Yellow Time} \leq 6 \text{ sec}$

$$\text{All-Red Time (sec)} = \frac{W + L}{1.47V} - 1$$

### **Equation 15-2 All-Red Time**

Source: *NCHRP Report 731*

Where:

*W = width of the intersection (ft); measured from the stop line to the far edge of the farthest traveled lane of cross-street traffic. For left turn phases, use approximate travel path of turning vehicle and measure to far edge of conflicting traffic. If a pedestrian crossing is 40 feet or more from the extension of the farthest edge of the farthest conflicting traffic lane, then W should be measured from the stop line to the nearest pedestrian crossing line.*

*V = 85<sup>th</sup> percentile speed (mph); if not available use posted speed plus 7 mph for through phases or 20 mph for left turn phases.*

*L = length of vehicle (ft); set at 20 ft; consider using appropriate truck length for movements with significant truck traffic*

$$1 \text{ sec} \leq \text{All-Red Time} \leq 6 \text{ sec}$$

Yellow and All-Red Time shall be rounded to the nearest half-second according to the following:

- Values ending in 0.1 should be rounded down to the nearest whole number;
- Values ending in 0.2, 0.3, and 0.4 should be rounded up to the half-second;
- Values ending in 0.6 should rounded down to the half-second; and,
- Values ending in 0.7, 0.8, and 0.9 should be rounded up to the nearest whole number.

**Pedestrian Phase Time**

The calculation of pedestrian phase times shall be as per the MUTCD. The WALK display time should be 7-seconds. For minimal pedestrian volumes, a WALK display time of 5-seconds may be used. The flashing DON'T WALK display should terminate at the beginning of the yellow phase; the All-Red time is not included in the MUTCD buffer interval.

## **TRAFFIC ANALYSIS SOFTWARE**

### **Highway & Intersection Capacity**

Only software that has been accepted by the FHWA as fully compliant with the methodologies of the *Highway Capacity Manual* (HCM) shall be used to evaluate capacity and levels of service. Presently, only the HCM analysis software developed by the McTrans Center has been accepted by the FHWA. HCM intersection analyses for planning studies shall use the PHF method. Operational analyses for undersaturated conditions shall use the 4 X peak 15 minute period volumes and a PHF of 1. Operational analyses for near or over saturated conditions shall use the multi-period method. The following parameters should be used in place of the software default values:

Peak Hour Factor (PHF) – use overall intersection PHF for all movements.

Start-up Lost Time - use 3 seconds per cycle.

Extension of Effective Green - use 3 seconds per cycle (field measure if possible).

Right Turns on Red - field measure if possible.

Ideal Saturation Flow Rate – in rural areas use up to 1700; in urban and suburban areas use up to 1900

Percent Heavy Vehicles – use actual data if available; consult with Transportation Inventory Management for available data.

Highest Single Lane Volume in Lane Group – use observed data if available.

### **Traffic Signal Phasing Design**

The SDDOT uses Trafficware's Synchro software for designing traffic signal phasing. The parameters cited above for the McTrans Center software should also be used in Synchro. The level of service results provided by Synchro are not to be used for reporting purposes.

### **Traffic Simulation**

The SDDOT uses VISSIM, CORSIM, and SimTraffic software for traffic simulation. Because each software has particular strengths for certain applications, the determination of which to use is project specific. For more detailed information on the use of software, please refer to the FHWA's *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software*.

## TRAFFIC SIGNAL WIRING

### Conduit

All signal cable is placed in conduit; 4" conduit is the minimum size used between the controller and the junction box, 3" conduit is the minimum size used under the roadway and 2" conduit is usually placed between junction boxes and signal poles. When in doubt of what conduit size to use, size the conduit using the following equation:

$$1.58 \times \sqrt{d_1^2 + d_2^2 + d_3^2 + d_4^2 + \dots d_x^2}$$

**Equation 15-3** Conduit Size

Where  $d_1, d_2, d_3, d_4, \dots d_x$ , is the diameter of the cables in the conduit to be sized.

Table 15-14 gives the diameters and diameters squared for several cables.

**Table 15-14** Cable Diameter and Diameter<sup>2</sup>

Cable	d	d <sup>2</sup>	Cable	d	d <sup>2</sup>
24/c #14	0.8350	0.6972	TSP	0.4000	0.1600
24/c #12	0.9950	0.9900	1/c #14	0.1300	0.0169
20/c #14	0.7850	0.6162	1/c #12	0.1600	0.0256
20/c #12	0.9100	0.8281	1/c #10	0.2000	0.0400
19/c #14	0.7500	0.5625	1/c #8	0.3300	0.1089
19/c #12	0.9000	0.8100	1/c #6	0.4000	0.1600
12/c #14	0.6500	0.4225	1/c #4	0.4500	0.2025
12/c #12	0.7500	0.5625	1/c #2	0.5100	0.2601
7/c #12	0.5200	0.2704	1/c #1	0.6000	0.3600
7/c #14	0.4600	0.2116	1/c #0	0.7000	0.4900
4/c #14	0.4000	0.1600	1/c #00	0.7600	0.5776

An Excel workbook to calculate Equation 15-3 is available to aid in the design process.

Conduit for interconnect fiber optic cable should be a minimum of 2". Local water table conditions may require the use of innerduct within conduit to avoid excessive water infiltration.

## **Cable Size, Type, and Number**

Detector loops use 1 #16 twisted shielded pair (TSP) cable per loop. Consecutive lane loops at the stop bar require only 1 TSP.

Each luminaire mounted on a signal pole requires 3 #6 AWG copper cables. The 3 #6s run from the signal pole to the power source. The 3 #6s used for luminaire extensions do not accumulate.

3 #6 AWG copper cables are used from the power source to the controller cabinet. The voltage drop should be checked if the power source and the controller cabinet are a significant distance apart. A junction box is placed between the source and the controller cabinet. A secondary disconnect (i.e. safety switch) should be placed at the controller cabinet if the power source is not immediately adjacent to the controller cabinet. The disconnect should have two poles (for signal hot and luminaire extension hot) and be a single throw type.

Cables run uninterrupted from the controller to the signal poles. There should be enough conductors for each signal head and a minimum of four spare conductors in each pole. Each signal head requires one conductor per section plus one, e.g. 3-section vehicle heads require four conductors, etc. Pedestrian heads require three conductors and pedestrian push buttons require two conductors. Refer to the standard bid items for cable sizes used by the SDDOT. Cables are #14 AWG copper tray cables, color coded in accordance with ICEA standards; projects in Sioux Falls use IMSA color coding.

2/c cable is used for pedestrian push buttons.

3/c cable is used for pedestrian signal heads installed on pedestal signal poles.

3/c cable is used for an Opticom™ confirmation light mounted unit on a mast arm.

4/c cable is used for an Opticom™ receiver on a mast arm.

2/c cable is used for a Sonem (acoustic EVP) confirmation light.

TSP cable is used for Sonem microphones.

Single mode fiber optic cable is used for traffic signal interconnection. The number of fibers per cable is project dependent.

Individual #6 conductors are used for luminaire extension circuits.

#10 AWG pole and bracket cable is used within poles with luminaire extensions.

## **Cable Length**

Design lengths shall be as shown in Table 15-15.

**Table 15-15** Traffic Signal Cable/Conductor Design Length

<b>Feature</b>	<b>Design Length <sup>1</sup></b>
Push Button Poles	5'
Mast Arm Mounted Signal Head	Distance from Pole to Head + 22'
Pole Mounted Signal Head	15'
Pedestrian Signal Head	15'
Luminaire Extension	Mounting Height + Length of Luminaire Arm + 7'
Mast Arm Mounted Pre-emption Detector	Distance from Pole to Detector + 22'
Mast Arm Mounted Pre-emption Confirmation Light	Distance from Pole to Light + 22'
Cable/Conductor at Junction Box	Add 5' to each Cable/Conductor Entering & Exiting
Cable/Conductor at Signal Pole	Add 5' to each Cable/Conductor Entering & Exiting
Cable/Conductor at Controller Cabinet	Add 10' to each Cable/Conductor
Conductor at Electric Service Cabinet	Add 25' to each Conductor
Fiber Optic Cable at Junction Box	Add 7.5' to each Cable Entering & Exiting
Fiber Optic Cable at Controller Cabinet	Add 15'

<sup>1</sup>The values entered into the "TABLE OF CONDUIT AND CABLE QUANTITIES" shall be the calculated design lengths multiplied by 1.03 and rounded up to the nearest whole 5 feet.

## **Junction Boxes**

Type 3 junction boxes are typically used for traffic signal wiring. Type 4 boxes are used for interconnection conduits. Box spacing for interconnect systems is 400 - 500 feet, with boxes placed on each side of a road crossing.

In new construction, junction boxes should not be in walkways, curb ramps, turning space, transitions, and gutters within the pedestrian access route (PAR). For projects where the existing signal infrastructure is to remain in place, effort should be made to provide the most accessible PAR possible. Where junction boxes must be located on any portion of the curb ramp, they shall meet the surface requirements of the PAR (firm, stable, slip resistant, and flush). See Chapter 16, Miscellaneous, for detailed PAR guidelines.

## **TRAFFIC IMPACT STUDY GUIDELINES**

### **Introduction**

A traffic impact study (TIS) is a traffic engineering tool used to objectively assess the safety and operational impacts of development activities that propose to use the State highway system for access. The primary responsibility for assessing the traffic impacts associated with a proposed development rest with the developer, with the SD Department of Transportation (Department) serving in a review and approval capacity.

### **General**

Traffic impact studies shall be prepared by a South Dakota licensed Professional Engineer with experience in the field of traffic engineering. The developer or local government entity shall be responsible for the preparation of the TIS. The document shall fully describe the proposed development. Upon submission of a draft TIS the Department will review the study data sources, methods, and findings, and provide a written summary of review comments.

Traffic impact study approvals granted by the Department shall be valid for 2 years. If significant work on the development has not commenced within the approval period, the TIS shall be updated and resubmitted for review. Studies will be required to be updated within the 2 year approval period if the proposed land use(s) are significantly altered, or traffic volumes within the study area are increased by more than 15%.

### **Pre-study Conference**

Prior to the preparation of a TIS, the developer or the engineer preparing the TIS shall schedule a pre-study conference with the appropriate Area Engineer. The Area Engineer will coordinate attendance by the applicable Department offices, and if appropriate, local government staff and Federal Highway Administration staff. Outcomes of a pre-study conference may include, but are not limited to:

- Establishment of the study boundaries and study intersections.
- Confirmation of peak hour times.
- Confirmation of the study horizon years.
- Establishment of traffic growth factors.
- Establishment of design parameters, i.e. design speed, lane width, turn lane design, clear zone, design vehicle, etc. All parameters shall conform to the Department's *Road Design Manual*.
- Confirmation of trip assignment parameters.
- Agreement on internal capture rate and pass-by trip rates.
- Sharing of existing traffic data.
- Accommodation of pedestrian and bicycle needs in the study area and within the planned development area.
- Identification of other planned developments in the study area.
- Sharing of information on planned roadway improvements in the study area (from the Statewide Transportation Improvement Program (STIP) and Developmental STIP).
- Identification of analysis software.

Following the pre-study conference, the engineer preparing the TIS shall prepare and distribute a Methods & Assumptions Document detailing the agreed upon parameters.

### **Requirement Thresholds**

A TIS is required for any proposed development that is forecast to generate 100 or more trips during the adjacent highway's peak hour or the development's peak hour. Trip generation estimates shall be derived using values from the current *Institute of Transportation Engineers' Trip Generation Manual*, values from an approved alternative method, or existing traffic counts from similar land uses. The following table is a general guide for typical development types and sizes that would require a TIS:

**Table 15-16** Common Land Use Thresholds Generating 100 Peak Hour Trips

Land Use	Development Size
Single Family Homes	> 95 lots
Apartments	> 150 units
Condominiums/townhomes	> 190 units
Mobile Home Park	> 170 lots
Retail Shopping Center	> 6,000 square feet gross floor area
General Office	> 67,000 square feet gross floor area
Medical Office	> 31,000 square feet gross floor area
Industrial	> 150,000 square feet gross floor area
Fast Food	> 3,000 square feet gross floor area
Bank	> 3,900 square feet gross floor area
Gas Station w/Convenience Store	> 7 fuel pumps

The Department reserves the right to require a TIS for proposed developments not meeting the 100 trip threshold, or not directly accessing onto the State highway if, in its judgment, the trip generation characteristics of the proposed development are likely to have a significant negative impact on the safe and efficient operation of the State highway system.

### **Study Horizons**

Typically, a TIS should include operational analyses for:

- Development opening year.
- Full build out year.
- 20 years post full build out year.

Additional study horizon years will be required if the proposed development consists of multiple phases, planned to be implemented over several years.

### **Report Format & Contents**

Specific TIS requirements will vary depending on the location of the proposed development and other factors, however, all traffic impact studies shall (at a minimum) contain the following sections and information:

## **Introduction**

- Location map.
- Development size.
- General terrain features of the site.
- Adjacent roadways.
- Vicinity map indicating boundaries of study area as determined at the pre-study conference.
- Development phasing plan (if any).

## **Existing and Proposed Land Uses**

- Map of existing and proposed land uses for site; include zoning categories of the local government authority (if any).
- Map of existing land uses near the site; include zoning categories of the local government authority (if any).
- Map of proposed land uses near the site (if available).

## **Existing and Proposed Roadways and Intersections**

- Descriptions of existing roadways and intersections.
- Descriptions of any planned roadway or intersection improvements by others. Information on planned improvements may be found in the Statewide Transportation Improvement Program (STIP) and the Developmental STIP, or from the local governing entity.

## **Existing Traffic Volumes**

- Map showing daily traffic volume counts for study roadways. Unless existing counts are supplied by the Department, the engineer preparing the TIS shall be responsible for obtaining all traffic counts.
- Map showing peak hour turning movement counts for study intersections. Unless existing counts are supplied by the Department, the engineer preparing the TIS shall be responsible for obtaining all turning movement counts.
- Raw count data (in an appendix).

Traffic counts more than one year old will not be accepted. All total daily traffic counts should be actual machine counts and not based on factored peak hour sampling.

## **Existing Crash History**

- Tabular summary of the most recent 3 years of crash data adjacent to the development (roadway and intersection).
- Map of crash data.
- Identification of any access related crash trends and possible mitigation measures.

## **Evaluation of Existing Traffic Operations**

- Peak hour capacity analyses for study intersections. Pedestrians and bicycle traffic shall be considered in the analyses.
- Peak hour capacity analyses for arterials within the study area. Pedestrians and bicycle traffic shall be considered in the analyses.
- Analysis software output reports (typically in an appendix).

Capacity analyses will be calculated in accordance with the procedures outlined in *The Highway Capacity Manual*. Presented analyses results shall include Levels of Service (LOS) and Volume/Capacity ratios (V/C).

## **Access Points**

- Description of proposed new or revised access and explanation of the need for new or revised access point(s). Description shall include different alternatives considered for access and why the selected alternative was chosen. Chapter 17- Access Management contains detailed information about the Department's access management policies. Chapter 13-Interchanges, contains detailed information about policies governing access points adjacent to freeway interchanges.
- Evaluation of turning lane warrants for each access point, as found in this chapter. Geometric design parameters for turn lanes are contained in Chapter 12-Intersections.
- Comparison of available intersection sight distance at the proposed highway access points with the appropriate values in the current AASHTO publication *A Policy on Geometric Design of Highways and Streets* and the Department's *Road Design Manual* (Chapter 12-Intersections).
- Discussion of proposed mitigation measures for any values found to be deficient for the highway speed.

## **Forecast Background Traffic Volumes**

- Map showing daily traffic volume counts for study roadways, factored to the appropriate study horizon year.
- Map showing peak hour turning moment counts for study intersections, factored to the appropriate study horizon year.

The number of periods will coincide with the appropriate study horizons agreed upon at the pre-study conference.

## Evaluation of Traffic Operations with Forecast Background Volumes

- Peak hour capacity analyses for study intersections. Pedestrians and bicycle traffic shall be considered in the analyses.
- Peak hour capacity analyses for arterials within the study area. Pedestrians and bicycle traffic shall be considered in the analyses.
- Analysis software output reports (typically in an appendix).

Capacity analyses will be calculated in accordance with the procedures outlined in *The Highway Capacity Manual*. Presented analyses results shall include Levels of Service (LOS), Volume/Capacity ratios (V/C), and 95<sup>th</sup> percentile queue lengths.

Analyses shall consider all planned roadway improvements. Forecast changes in traffic control, e.g. future traffic signals, as identified at the pre-study conference shall also be taken into consideration as appropriate.

## Trip Generation

- Tabular summary of trips for each land use. If phased development is proposed, the study shall include projections for the year that each phase of the development is planned to be complete.
- For land uses expected to generate more than thirty (30) trucks per day: tabular summary of trip generation for trucks.
- Tabular summary of pass-by trips and internal trips.
- Tabular summary of trip generation data for any pending and approved developments that would affect the study area.

Trip generation factors shall be from the current *Institute of Transportation Engineers' Trip Generation Manual*. If data is not available for a proposed land use, the Department must approve the proposed factors.

The calculation of pass-by trips and internal capture rates shall be in accordance with the current *Institute of Transportation Engineers' Trip Generation Handbook*.

## Trip Distribution and Assignment

- Discussion of the technical analysis steps, basic methods, and assumptions used in developing trip assignment and distribution.
- Map showing the trip distribution and assignment in the study area.
- For developments expected to generate more than thirty (30) truck trips per day, include separate trip distribution figures for trucks.

## **Combined Background & Development Traffic Volumes**

- Map showing total background and development daily traffic volume counts for study roadways, factored to the appropriate study horizon year.
- Map showing total background and development peak hour turning movement counts for study intersections, factored to the appropriate study horizon year.

The number of periods will coincide with the appropriate study horizons agreed upon at the pre-study conference.

## **Evaluation of Traffic Operations with Combined Background & Development Traffic Volumes**

- Peak hour capacity analyses for study intersections. Pedestrians and bicycle traffic shall be considered in the analyses.
- Peak hour capacity analyses for arterials within the study area. Pedestrians and bicycle traffic shall be considered in the analyses.
- Discussion of mitigation measures for any intersections or arterials that do not meet the performance parameters outlined earlier in this chapter.
- Analysis software output reports (typically in an appendix).

Capacity analyses will be calculated in accordance with the procedures outlined in *The Highway Capacity Manual*. Presented analyses results shall include Levels of Service (LOS), Volume/Capacity ratios (V/C) and 95<sup>th</sup> percentile queue lengths. The minimum acceptable LOS shall be as defined in this chapter.

The analyses should consider any planned improvements, proposed mitigation measures, forecast changes in traffic control, e.g. new traffic signals, ALL-WAY STOPS, etc., and recommended changes in traffic control.

## **Traffic Signals**

- Evaluation of the need for any new traffic signals; evaluations shall use the appropriate warrants of the current *Manual on Uniform Traffic Control Devices*. For the purposes of evaluating the need for a traffic signal, hourly approach volumes based on a factoring of the peak hour counts will be permitted.
- Warrant evaluation software summaries (typically in an appendix).
- Statement that a traffic signal is not recommended to be installed until a detailed engineering study of conditions has been completed.

Phasing and other operational parameters used in the capacity analyses shall follow the signal design guidelines presented elsewhere in this chapter. Future signals that are within an existing coordinated system shall consider progression and provide for optimum signal progression.

## **Non-Motorized Traffic**

- Discussion of the development's impact to, and accommodations for, pedestrian travel and access. While the focus of the discussion should be on the State highway right-of-way, it will likely be beneficial to include any accommodations internal to the development.
- Discussion of the development's impact to, and accommodations for, bicyclist travel and access. While the focus of the discussion should be on the State highway right-of-way, it will likely be beneficial to include any accommodations internal to the development.

## **Conclusions & Recommendations**

- Summary of the study findings.
- Summary description of recommended roadway and intersection improvements to remedy deficiencies. All associated design and construction costs for the mitigation measures shall be the responsibility of the developer. Note that all design parameters shall conform to the current AASHTO publication *A Policy on Geometric Design of Highways and Streets* and the Department's *Road Design Manual*.
- Graphical overview with dimensions of recommended roadway and intersection improvements, clearly showing the changes. The location of proposed access points should also be shown. This figure should be capable of standing alone as a "before and after" diagram of roadway configuration.
- Summary of recommended traffic control changes.

This section should be viewed as being the executive summary of the TIS and should strive to be as complete and concise as possible.

## **Revisions to Traffic Impact Study**

The need to require revisions will be based on the completeness of the TIS, the thoroughness of the impact evaluation, and the compatibility of the study with the development plans. Any Department comments/revisions to the TIS must be completely addressed prior to an approval being issued. Revised versions of the TIS shall include as an appendix a memorandum describing the responses to the Department's comments.

## **LIGHTING WARRANTS**

### **General**

The installation of roadway lighting should be considered if one or more of the warrants listed below are met. Note, however, that the satisfaction of a warrant or warrants is not in itself justification for roadway lighting to be installed. An engineering study should be completed to determine if the installation of roadway lighting would improve the overall safety and/or operation of the intersection or roadway. Irrespective of the warrants evaluation and the study, engineering judgement may alter the need and/or extent of a lighting project.

For further information on the development of lighting projects, cost sharing, and maintenance responsibilities see the Department's "Lighting on State Highways" policy.

### **Definitions**

- Urban: Areas with a US Census population greater than 5,000.
- Rural: Areas with a US Census population less than 5,000.

### **Warrants for Roadway Lighting**

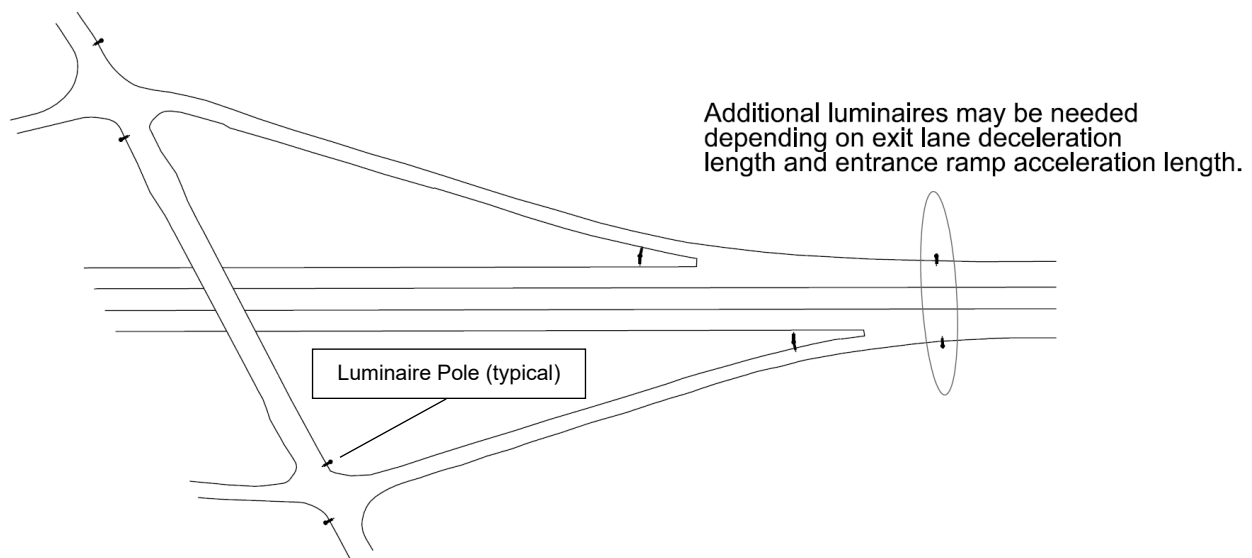
1. Existing Lighting Level Warrant – this warrant is satisfied when an existing lighting system fails to provide adequate illumination levels, or when background lighting creates glare or other undesirable conditions.
2. Crash Experience Warrant – this warrant is satisfied when two or more nighttime crashes occurred in the past 12-month period or three or more nighttime crashes occurred in the past 36-month period, and it is deemed that roadway lighting would reduce the frequency of such crashes.
3. Pedestrian Warrant – this warrant is satisfied when significant nighttime pedestrian movement occurs on a regular basis.

### **Warrants for Intersection Lighting**

1. Volume Warrant – this warrant is satisfied when the current combined ADT entering the intersection is greater than 4,000 vpd and the number of conflicting vehicle or pedestrian movements occurring within the intersection is deemed excessive.
2. Crash Experience Warrant – this warrant is satisfied when two or more nighttime crashes occurred in the past 12-month period or three or more nighttime crashes occurred in the past 36-month period and it is deemed that intersection lighting would reduce the frequency of such crashes.

3. Traffic Signal Warrant – this warrant is satisfied if a traffic signal is installed at the intersection.
4. Geometrics Warrant – this warrant is satisfied if sight distance, horizontal alignment, vertical alignment, channelization, auxiliary turn lanes, or other factors negatively affect driver comprehension and it is deemed that intersection lighting would enhance operations.
5. Existing Lighting Level Warrant – this warrant is satisfied when an existing lighting system fails to provide adequate illumination, or when background lighting creates glare or other undesirable conditions.
6. Pedestrian Warrant – this warrant is satisfied when significant nighttime pedestrian movement occurs on a regular basis.
7. Railroad Warrant – this warrant is satisfied if a railroad crossing is adjacent to the intersection.

### **Warrants for Partial Interchange Lighting**



**Figure 15-8** Schematic Layout of Partial Interchange Lighting

1. Development Warrant – this warrant is satisfied if the interchange has significant traveler-focused development adjacent to it, e.g. lodging, gas stations, fast-food, etc.
2. Volume Warrant – this warrant is satisfied when the current ADT on any Interstate ramp is greater than 5,000 vehicles per day (vpd) for urban conditions or 1,000 vpd for rural conditions.

3. Existing Lighting Level Warrant – this warrant is satisfied when off right-of-way lighting creates undesirable light conditions.
4. Crash Experience Warrant - this warrant is satisfied when two or more nighttime crashes occurred in the past 12-month period or three or more nighttime crashes occurred in the past 36-month period, and it is deemed that partial interchange lighting would reduce the frequency of such crashes

### **Warrants for Full Interchange Lighting**

Full interchange lighting builds upon the layout for partial interchange lighting, adding illumination along all ramps. Full interchange lighting may use standard luminaire poles, high mast lighting, or a combination of the two.

- 1) Volume Warrant – this warrant is satisfied when the current ADT on the Interstate mainline is greater than 10,000 vpd for urban conditions or 5,000 vpd for rural conditions and the current ADT on the crossroad is greater than 10,000 vpd for urban conditions or 5,000 vpd for rural conditions.
- 2) Existing Lighting Level Warrant – this warrant is satisfied when the crossroad has roadway lighting for ½ mile or more on both sides of the interchange.
- 3) Crash Experience Warrant – this warrant is satisfied when two or more nighttime crashes occurred in the past 12-month period or three or more nighttime crashes occurred in the past 36-month period, and it is deemed that full interchange lighting would reduce the frequency of such crashes

### **Warrants for Continuous Interstate Lighting**

1. Volume Warrant – this warrant is satisfied when the current ADT for the Interstate is greater than 25,000 vpd.
2. Interchange Spacing Warrant – this warrant is satisfied if three or more successive lighted interchanges exist with an average spacing of 1.5 miles or less, and the adjacent land uses are urban in character.
3. Existing Light Level Warrant – this warrant is satisfied when existing lighting in the area creates glare or other undesirable conditions.
4. Crash Rate Warrant – this warrant is satisfied when it is deemed that continuous lighting would significantly reduce the nighttime crash rate.

## STANDARD LIGHTING DESIGN

### Light Level and Uniformity

The SDDOT uses the Illuminance Method to design lighting systems; the evaluation of lighting uniformity also uses the maximum/minimum ratio values from the Luminance Method. The design light level for standard and decorative lighting systems is based on Tables 15-17-21

**Table 15-17** Road Surface Classifications

<b>Class</b>	<b>Q<sub>o</sub>*</b>	<b>Description</b>	<b>Mode of Reflectance</b>
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 12 percent of the aggregates composed of artificial brightener (e.g., Syopal) aggregates (e.g., labradorite, quartzite)	Mostly diffuse
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular

Source: AASHTO Roadway Lighting Design Guide

**Table 15-18 Recommended Design Values**

Roadway and Walkway Classification (1)	Off-Roadway Light Sources	Average Maintained Illuminance (2,3)		Minimum Illuminance  (foot-candles)	Uniformity Ratios		Veiling Luminance Ratio  Lv(max) / Lavg(max) (5)
	General Land Use (6)	R1 (foot-candles) (min)	R3 (foot-candles) (min)		avg/min (max) (4)	max/min (max)	
Interstate and Other Freeways	All	0.6	0.6	0.2	4:1	6:1	0.3:1
Other Principal Arterials (partial or no control of access)	Commercial	1.1	1.6	As uniformity ratio allows	3:1	5:1	0.3:1
	Intermediate	0.8	1.2		3:1	5:1	0.3:1
	Residential	0.6	0.8		3:1	6:1	0.3:1
Minor Arterials	Commercial	0.9	1.4		4:1	5:1	0.3:1
	Intermediate	0.8	1.0		4:1	5:1	0.3:1
	Residential	0.5	0.7		4:1	6:1	0.3:1
Collectors	Commercial	0.8	1.1		4:1	5:1	0.4:1
	Intermediate	0.6	0.8		4:1	6:1	0.4:1
	Residential	0.4	0.6		4:1	8:1	0.4:1

1. See AASHTO *A Policy on Geometric Design of Highways and Streets*.
2. There may be situations when a higher level of illuminance is justified. The higher values for freeways may be justified when deemed advantageous by the agency to mitigate off-roadway sources.
3. Physical roadway conditions may require adjustment of spacing determined from the base levels of illuminance indicated above.
4. Higher uniformity ratios are acceptable for elevated ramps near high-mast poles.
5. Lv(max) refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the Lv term and the Lavg term.
6. Commercial – An area that typically has large numbers of pedestrians and a heavy demand for parking spaces during periods of peak traffic, or a sustained high pedestrian volume and a continuously heavy demand for off-street parking during business hours. This definition applies to densely developed business areas outside of, as well as those that are within the central part of a municipality.

Intermediate – An area that is within the zone of influence of a business or industrial development, often characterized by a moderately heavy nighttime pedestrian traffic and a somewhat lower parking turnover than is found in a larger or more active commercial area.

Residential - An area characterized by few pedestrians and low parking demand or turnover at night or portions of the night. Although this definition includes areas with housing, it also includes commercial areas with low pedestrian activity.  
Source: *AASHTO Roadway Lighting Design Guide*

**Table 15-19** Recommended Design Values for Intersections within Lighted Segments

Roadway Classifications <sup>(1)</sup>	Average Maintained Illuminance (foot-candles)			avg/min (max)
	High Pedestrian Activity Area <sup>(1)</sup>	Medium Pedestrian Activity Area <sup>(1)</sup>	Low Pedestrian Activity Area <sup>(1)</sup>	
Major/Major	3.4	2.6	1.8	3:1
Major/Collector	2.9	2.2	1.5	3:1
Major/Local	2.6	2.0	1.3	3:1
Collector/Collector	2.4	1.8	1.2	3:1
Collector/Local	2.1	1.6	1.0	3:1
Local/Local	1.8	1.4	0.8	3:1

1. See IES RP-8-14.

Source: *IES American National Standard Practice for Roadway Lighting RP-8-00*

**Table 15-20** Recommended Design Values for Isolated Intersections, Interchanges, and Railroad Grade Crossings

Roadway Classification <sup>(1)</sup>	Pavement Classification		avg/min (max)
	R1	R3	
	(foot-candles) (min)	(foot-candles) (min)	
Freeway Class A	0.6	0.9	3:1
Freeway Class B	0.4	0.6	3:1
Expressway	0.6	0.9	3:1
Major	0.6	0.9	3:1
Collector	0.4	0.6	4:1
Local	0.3	0.4	6:1

1. See IES RP-8-14.

Source: *IES American National Standard Practice for Roadway Lighting RP-8-00*

**Table 15-21** Recommended Design Values for Roundabouts

Roadway Classifications <sup>(1)</sup>	Average Maintained Illuminance (foot-candles)			avg/min (max)
	High Pedestrian Activity Area <sup>(1)</sup>	Medium Pedestrian Activity Area <sup>(1)</sup>	Low Pedestrian Activity Area <sup>(1)</sup>	
Major/Major	3.4	2.6	1.8	3:1
Major/Collector	2.9	2.2	1.5	3:1

Major/Local	2.6	2.0	1.3	3:1
Collector/Collector	2.4	1.8	1.2	4:1
Collector/Local	2.1	1.6	1.0	4:1
Local/Local	1.8	1.4	0.8	4:1

1. See IES RP-8-14.

Source: *IES American National Standard Practice for Roadway Lighting RP-8-00*

## **Light Sources**

Either high pressure sodium (HPS) luminaires or light emitting diode (LED) luminaires should be used. The use of other types of luminaires is subject to the provisions of the Department's "Lighting on State Highways" policy. All luminaires shall be controlled by individual photoelectric cells. The use of lighting contactors may be considered on a project specific basis.

## **Mounting Height and Wattage**

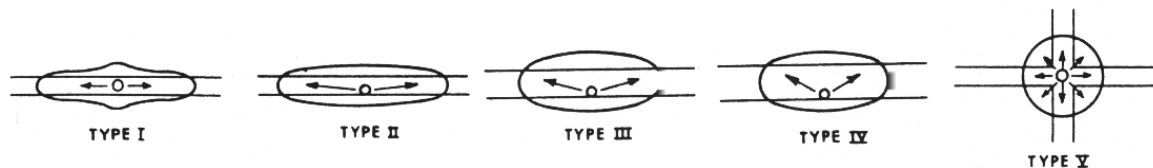
The mounting height is the distance from the roadway surface to the luminaire. Mounting height affects the illumination intensity, uniformity of brightness, area covered, and relative glare of the unit. Higher mounted luminaires provide greater coverage, more uniformity, and a reduction of glare, but a lower foot-candle level. By using higher poles, fewer poles are required and they can be set back farther from the traveled roadway. Generally, pole heights range from 40'-50' for standard roadway lighting, with mounting heights specified in 5' increments. Pole height selection should take into consideration adjacent overhead utilities, airports, and the ability of the local municipality to maintain the luminaires.

The required luminaire performance characteristics vary depending on the mounting height selected. For HPS luminaires, performance is relatively consistent for given standard lamp wattages. For mounting heights 40-feet or less, the usual HPS luminaire size is 250 W. For mounting heights of 45 and 50-feet, the usual HPS luminaire size is 400 W.

Other than color temperature, the performance characteristics of LED luminaires are not yet as consistent industry-wide as those of HPS luminaires (the standard color temperature for lighting on state highways is 4000K). Consequently, the design of LED lighting systems must carefully consider the luminaire's photometric properties in order to achieve the appropriate light levels, while at the same time minimizing the number of poles needed and minimizing energy consumption.

## **Light Distribution**

The lateral light distributions are categorized by patterns established by the Illuminating Engineering Society of North America (IESNA) and designated as Types I, II, III, IV, and V as shown below in Figure 15-7.



**Figure 15-9** Lateral Light Distributions

Type I applies to rectangular patterns on narrow streets. Type II applies to narrow streets. Type III applies to streets of medium width. Type IV applies to wide street applications. Type V applies to areas where light is to be distributed evenly in all directions. Types I and V are generally mounted over the area to be lighted; Types II, III, and IV are generally mounted near the edge of the area to be lighted.

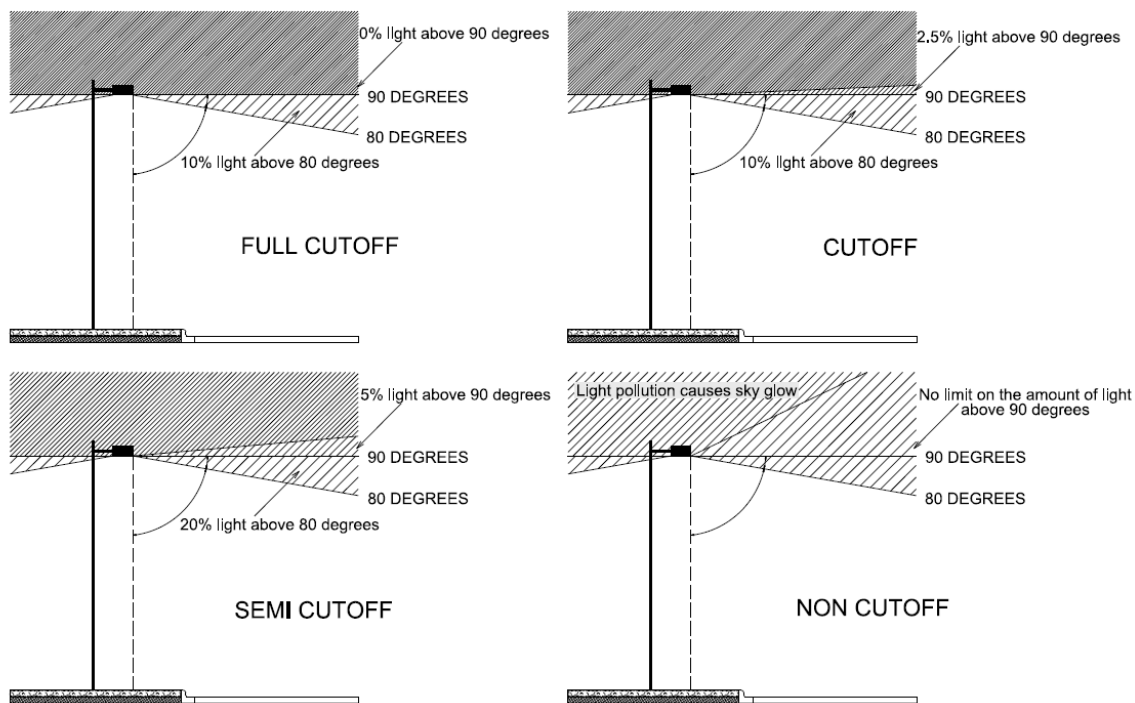
High pressure sodium luminaires are also categorized according to four classifications established by the IESNA to distinguish the range in quantity of upward light and light emitted above a horizontal plane:

Non-Cutoff - luminaires emit light in all directions; non-cutoff luminaires create the widest spread of light.

Semi-Cutoff – luminaires emit up to 5% of their light upward (at or above 90 degrees), and up to 20% of their light at or above 80 degrees; semi-cutoff luminaires create a wider spread of light.

Cutoff – luminaires emit up to 2.5% of their light upward (at or above 90 degrees) and up to 10% of their light at or above 80 degrees.

Full cutoff – luminaires do not emit any upward light (at or above 90 degrees) and up to 10% of their light at or above 80 degrees. Full cutoff luminaires create the narrowest spread of light.



**Figure 15-10** Luminaire Cutoff Classifications

Cutoff luminaires are typically used for partial interchange lighting and rural intersection lighting due to the reduced amount of glare created.

Semi-cutoff luminaires are typically used for standard roadway lighting. Glare issues are accommodated by proper spacing design.

Non-cutoff luminaires are used in areas with high levels of background light. Pole height is critical when using non-cutoff luminaires due to the potential to create excessive glare.

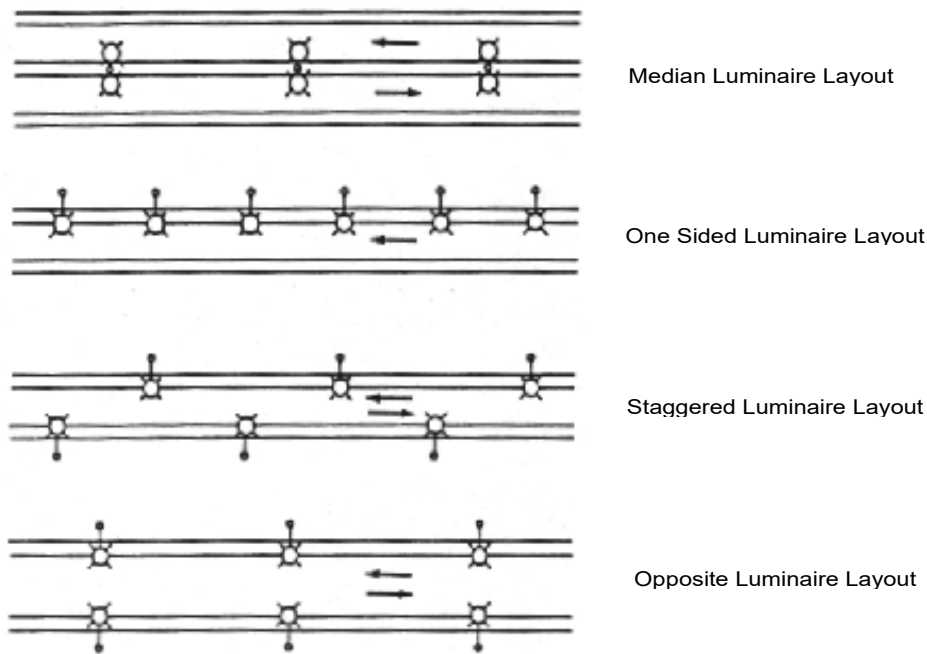
### **Lighting Design Software**

SDDOT uses AGi32™ software to design lighting systems. The roadway geometrics, luminaire photometric data, lumens/luminaire, a light loss factor, layout type, mounting height, setback, tilt, uniformity ratios, veiling ratio and the design light level are entered into the program to calculate the spacing and uniformity of a specific luminaire.

HPS Total Light Loss Factor – 0.70 total light loss factor for design of roadway lighting.

LED Total Light Loss Factor – 0.80 total light loss factor for design of roadway lighting.

Layout Type – The luminaire layout needs to be chosen relative to the roadway geometry; several possible layouts are shown below in Figure 15-9.



**Figure 15-11** Roadway Luminaire Layout Types

**Setback** – The distance between the luminaire and the edge of the targeted design area (typically the travelled way). The design should place the luminaires as close as possible to the area being illuminated.

**Tilt** – The angle of the luminaire. Standard roadway luminaires, cobra heads, cannot be tilted.

### **Luminaire Poles**

Luminaire poles for standard roadway lighting systems are typically galvanized steel. The use of decorative finishes is subject to the provisions of the Department’s “Lighting on State Highways” policy. All luminaire poles located within a highway’s clear zone shall have breakaway bases. Fixed bases are acceptable for luminaire poles adjacent to parking areas or for those that are barrier mounted.

### **Conductor Size and Type**

Standard roadway lighting luminaires are wired using two different configurations called “dual hots” and “alternating hots.” Dual hots are used when there are not any festoon outlets to be wired with the luminaire, i.e. 240V. Alternating hots are used when there are festoon outlets to be wired with the luminaire, i.e. 120V.

Conductor size is determined based on a maximum voltage drop of 5%, evaluated using Ohm’s Law.

Typical line-operating amperes for HPS luminaires are shown in Table 15-19. Line operating amperes for LED luminaires vary by manufacturer and should be obtained from specific product data sheets.

**Table 15-22** HPS Ballast Electrical Data

	120V, 60Hz	240V, 60Hz
Lamp Size (Watts)	Line Operating Amperes	
100	1.2	0.6
150	1.7	0.9
250	2.7	1.4
400	4.1	2.1
1000	9.6	4.8

Source: *General Electric Co.*

The SDDOT does not use any conductor smaller than #6 AWG copper for lighting circuits; #10 AWG pole and bracket is used within the pole itself.

Cable is typically placed in conduit. Schedule 40 PVC conduit is used for areas outside of roadways; Schedule 80 PVC conduit is used under roadways.

Conduit for lighting is sized as it is for signals (see Equation 15-3).

## **Cable Length**

**Table 15-23** Lighting Cable/Conductor Design Length

<b>Feature</b>	<b>Design Length <sup>1</sup></b>
Luminaire Pole	Height of Pole + Length of Luminaire Arm + 7'
Cable/Conductor at Junction Box	Add 5' to each Cable/Conductor Entering & Exiting
Cable/Conductor at Luminaire Pole	Add 5' to each Cable/Conductor Entering & Exiting
Conductor at Electric Service Cabinet	Add 25' to each Conductor
Festoon Outlet Hot Conductor	Height of Pole + Length of Luminaire Arm + 7' – Mounting Height of Outlet (typically 15')
Festoon Outlet Neutral & Ground Conductors	Mounting Height of Outlet (typically 15') + 7'

<sup>1</sup> The values entered into the plan "TABLE OF CONDUIT AND CABLE QUANTITIES" shall be the calculated design lengths multiplied by 1.03 and rounded up to the nearest whole 5-feet

## **Junction Boxes**

Junction boxes should be placed approximately every 400 ft. in a lighting circuit if there are no intervening luminaire poles with breakaway bases. Junction boxes shall be placed adjacent to luminaire poles with transformer bases if the number or size of conductors entering and exiting the pole will make future maintenance activities difficult. Junction boxes are required at all splice points that occur outside transformer bases. Sizing of the junction box should take into consideration the number of conductors entering and exiting the box.

## **Fuse Size**

A 10 ampere fuse should be used on each hot conductor in the luminaire pole base. The fuse size may be different if necessary to match the maintaining agency's standard.

## **Festoon Outlets**

Festoon outlets can be fed either concurrently from the luminaire circuit (i.e. alternating hots described earlier) or from separate circuits. Conductors for separate circuits should be sized for a maximum voltage drop of 5% assuming a 1.5 A load per outlet; the minimum conductor size should be #14 AWG copper.

## HIGH MAST LIGHTING DESIGN

### General

High mast lighting consists of groups of area type luminaires mounted on poles greater than 75-feet tall. High mast lighting is used for interchange lighting, rest areas and parking areas. It can also be used to light at-grade intersections of major highways.

### Light Level and Uniformity

The design light level chosen is based on Table 15-24 below.

**Table 15-24** Light Level Recommendations <sup>1</sup>

<b>Roadway and Sidewalk Classification</b>	<b>Average Light Level (fc)</b>	<b>Uniformity (Avg/Min.)</b>
Interchange	See Table 15-17	See Table 15-17
Rest Area	1.0	4:1
Parking Lot	0.8	4:1

<sup>1</sup> Higher lighting levels may be required after consideration of such factors as complexity, nearby existing lighting sources, and the prevailing lighting level on connecting or nearby roadways.

### Light Source

High Pressure Sodium (HPS) lamps are typically used. Advances in LED technology now allow the use of LED light sources in certain instances. The designer should choose the most economical light source for the conditions.

### **Mounting Height**

The mounting height is the distance from the roadway surface to the luminaire. High mast lighting systems have mounting heights varying from 80' to 150'. Generally, towers are 150' high for interchange lighting. Mounting heights are usually specified in 5' increments.

### **High Mast Location**

The SDDOT uses AGi32™ software to design high mast lighting systems. The roadway geometrics, luminaire photometric data, lumens/luminaire, a light loss factor, layout type, mounting height, setbacks, tilt, uniformity ratio, veiling ratio and the design light level are entered into the program to calculate the spacing and uniformity of a specific tower/luminaire combination.

The location of light towers is determined in the design process and by field conditions. Towers placed within a highway's clear zone must be shielded in accordance with the guidelines of Chapter 10 - Roadside Safety.

### **Conduit and Wire Size**

Conduit and wire is sized in the same way as for standard lighting.